Soft-Edged Magnet Models for Marylie/Impact*

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Abstract

The soft-edged magnet models that have been incorporated into the charged-particle transfer-map code Marylie are briefly described, and plans for future work with soft-edged magnet models in the code Marylie/Impact are outlined.

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Soft-Edged Magnet Models

- Used in numerical map computation for beamline systems with arbitrary magnetostatic elements.
- A flexible alternative to concatenation of maps for "canned" hard-edged beamline elements (the standard Marylie beamline element menu).
- Allows arbitrary superposition of fields in space (octupole correctors inside quadrupole lenses, etc.
- Exact high-order treatment of fringe-field effects.
- Soft-edged model approach is indispensable for some beamline design problems.
- Compute transfer maps either in the form of products of polynomial Lie transformations or as a Taylor series.
- The equations of motion for the map coefficients form a set of coupled nonlinear ODEs that contain the Taylor-series expansion coefficients of the magnetic vector potential. Also integrate reference trajectory.
- The Taylor-series expansion coefficients of the magnetic vector potential are provided to the map integration subroutines by the soft-edged magnet model routines.

Where Soft-Edged Field Models Matter

- Exact modeling of quadrupole magnetic lenses.

  - Soft-edged model needed for exact solution even of first-order problem with the real magnets (can always find equivalent hard-edged magnets and drifts for the first order problem, but only after the fringe-field profiles are known.

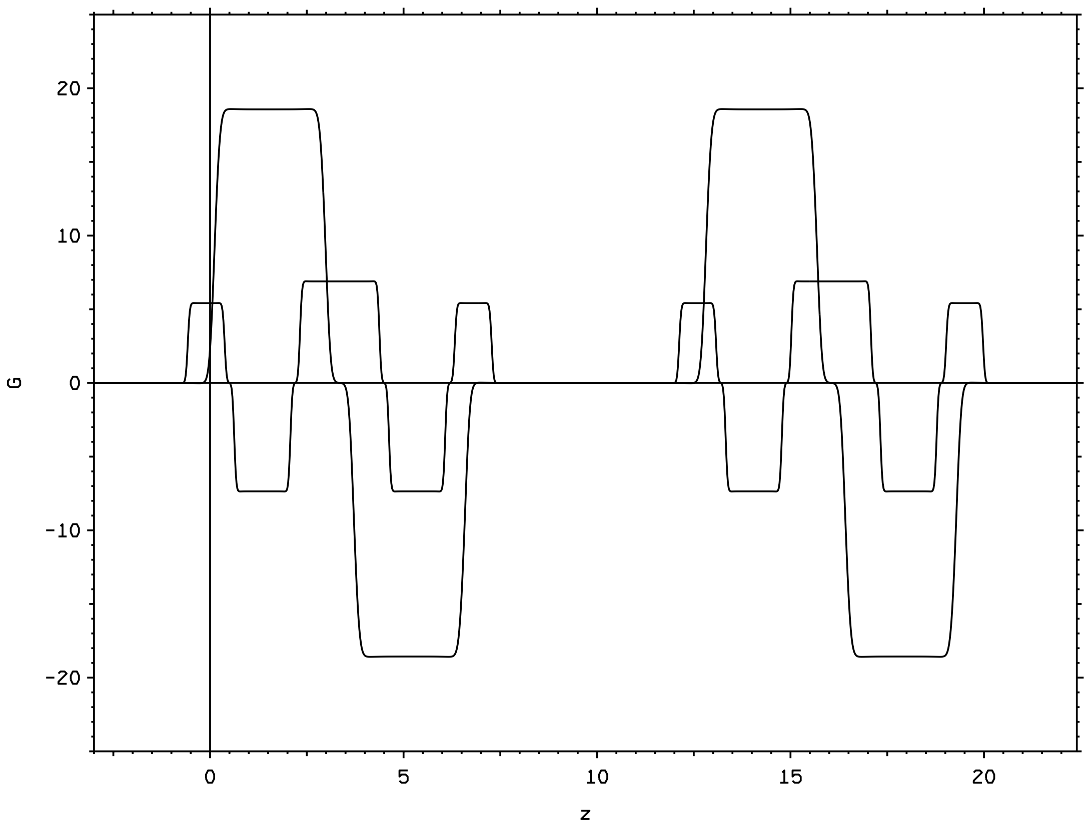
  - Worse problem if the magnets are so close that the fringe fields overlap- then cannot use GL of isolated magnets.

  - Need soft-edged models to get more accurate 3rd-order kicks than hard-edged models.

  - *Must* have soft edge model for 5th and higher order fringe-field effects in quadrupoles, sextupoles, and dipoles.
- Modeling wiggler fields (there are essentially no 2-D field zones)
- Modeling interaction region inserts- colliding beam accelerators.
- Modeling and design of magnetic spectrometers.

Example of Use of Numerically Integrated Map: Overlapping Soft-Edged Quadrupoles and Octupoles

- Magnetic lens with octupole correction of 3rd-order aberrations.
- Quadrupole and octupole gradient profiles are shown below.
- Adjusted quadrupole strengths to focus lens and octupole strengths to zero out selected Lie polynomial coefficients of the map.



Interface with the Numerical Map Integration Routines

- Modular program approach. Various soft-edged models can be called by the same map generation routines.
- 3-D fields with sin $m\phi$ symmetry, straight-axis systems:
  - The Taylor expansion coefficients of the vector potential are generated from the on-axis gradient g_m and its z derivatives.
  - Compute on-axis gradient g_m and its z derivatives from analytic function or explicit sources outside of beam region.

$$V(r,\phi,z) = \sum_{m=1}^{\infty} \sin m\phi \, V_m(r,z)$$

$$g_m(z) = \lim_{r \to 0} \frac{m V_m(r,z)}{r^m}$$

Interface with the Numerical Map Integration Routines

- 2-D fields with midplane symmetry (iron pole-piece dipole):
  - The Taylor expansion coefficients of the vector potential are generated from the midplane B_y and its z derivatives.
  - Compute midplane B_y and its z derivatives from analytic function or explicit sources outside of beam region. Use Helmholtz theorem to convert field data into sources.

$$A_z(x,y,z) = x\sum_{n=0}^{\infty}\frac{y^{2n}}{(2n)!}\left(-\frac{d^2}{dz^2}\right)^n B_y(z)$$

$$A_y(x,y,z) = -x\sum_{n=0}^{\infty}\frac{y^{2n+1}}{(2n+1)!}\left(-\frac{d^2}{dz^2}\right)^n \frac{d}{dz}B_y(z)$$

  - Generalize to 3-D midplane symmetric:

$$A_z(x,y,z) = -\sum_{n=0}^{\infty}\frac{y^{2n}}{(2n)!}\left(-\frac{\partial^2}{\partial x^2}-\frac{\partial^2}{\partial z^2}\right)^n \int_{x_0}^{x} b(x',z)dx'$$

$$A_y(x,y,z) = \sum_{n=0}^{\infty}\frac{y^{2n+1}}{(2n+1)!}\left(-\frac{\partial^2}{\partial x^2}-\frac{\partial^2}{\partial z^2}\right)^n \frac{\partial}{\partial z}\int_{x_0}^{x} b(x',z)dx'$$

Interface with the Numerical Map Integration Routines

- Elements with arbitrary symmetry:
  - Choose source surface, use Helmholtz theorem to get source strengths (elementary dipoles and monopoles) from surface fields
  - Use Dirac monopole vector potentials.
  - Get vector potential and its x and y derivatives by direct superposition of vector potentials and their x and y derivatives from the elementary sources.
  - Described in ICAP 2000 paper, Dragt, Walstrom, et al.
  - Improve accuracy and speed of method by use of piecewise continuous interpolation functions, subtracting dominant field analytically.
  - More work needed to implement practical version.

Soft-Edged Model Status

- Existing code capability is limited to 3-D fields with sin $m\phi$ symmetry, straight-axis systems.
  - Straight reference trajectory
  - Used to represent soft-edged fields of quadrupoles, sextupoles, etc. and straight current-dominated dipoles (e.g., superconducting accelerator ring dipoles). Pure m=1 case (dipole) has a very different fringe field from the 2-D dipole.
  - Have menu of approximate current-dominated magnet models, also can accept measured field data (B_r on a cylinder, etc.)
  - Also have model for Halbach-type PM multipole magnets.
- Ongoing and future work:
  - Consolidate and simplify existing models, add "canned" models based on measured data from typical beamline magnets.
  - Add dipole elements with a curved reference trajectory, 2-D fringe fields (iron pole-piece dipoles).
  - "Canned" fringe fields and user-provided fringe fields for dipoles.
  - Parallel-face and sector dipole magnets.
  - 3-D fields in iron-pole-piece dipoles.
  - Maps from measured or computed fields for magnetostatic elements with arbitrary symmetry (Helmholtz theorem)